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# A New Adaptive PMU based protection scheme for interconnected transmission network system

**Sayali N. Muneshwar[1], R. P. Hasabe[2]**

[1]P.G. Student, Dept. of Electrical Engg. Walchand College of Engineering, Sangli (M.S.), India
Sayali.muneshwar@gmailcom

[2]Assistant Professor, Dept. of Electrical Engg. Walchand College of Engineering, Sangli (M.S.), India
rphasabe@yahoo.co.in

**Abstract- This paper proposes a new adaptive phasor measurement unit (PMU) based protection scheme for wide area interconnected transmission lines network. This method uses positive sequence voltage and current phasors at both ends of a transmission line to determine the faulted area on the transmission line. The DFT (discrete Fourier transform) is used to compute the phasors of voltages and currents. High accuracy in fault location is achieved by using PMUs placement over a wide area measurement transmission system. This scheme gives the overall snapshot of the system by time synchronizing the data from all remote stations by using communication channel. The conventional system is not able to satisfy the time-synchronized requirement of power system. Phasor Measurement Unit (PMU) is enabler of time-synchronized measurement, it communicate the synchronized local information to remote station. This paper features simulation of interconnected network system for 220 KV line using MATLAB Simulink.**

***Index Terms— Wide Area Measurement System (WAMS), Global positioning system (GPS), synchrophasor, Phasor Measurement unit (PMU), time synchronization.***

## I. INTRODUCTION

The electrical power system is not a simple thing it's a complex man-made system so it has many problems whereas on the other end, it should reliable and supply electrical energy continuously without any interruption. There should be no blackout and outage [1]. The blackouts and especially infrequent outages is a combination of series of interrelated events. These series of events are hard to account even with modern powerful systems and can no longer be contained to the small portion of the system. Sometimes these small events or disturbances can be amplified to a system wide effect. Therefore for this purpose many techniques have been developed to survive the power system during disturbances and to continue its operation [2]. The conventional methods are not sufficient to provide the time synchronized data. Due to this reason, engineers are unable to reach and detect the exact location of the fault in the huge system. Many different techniques are introduced in the power system for the protection of the transmission line. One of the most widely used techniques in the power system is distance protection. In distance protection, the distance relay is used and it is based on standalone decision, while each relay operates independently according to different zone of protection. The distance relay is designed to operate for fault occurring between the relay location and the selected reach point, and remains stable for all faults outside this region or zone [3]. To cope with this, current differential protection with GPS system is introduced in the wide area measurement system. In this, current differential protection utilizes wide area current data with time synchronism for the simultaneous current sampling at all remote terminals and data exchange among them. But due to the CT saturation, this technique also have disadvantage of time synchronism of data. One recent developed technique which is used is WAMS with time synchronized measurement. It is a technique which transports the local information of selected areas to the remote location to work against the promulgation of vast disturbances.

A huge number of publications are there for protection of transmission lines. But on the other side, there are few published on applications of wide area transmission lines protection. The technique suggested in the paper for wide area protection is using PMU. This new technology i.e. Phasor Measurement Unit (PMU) provides both magnitude and phase angle phasor information in real time [4]. Effective utilization of this new technology is very much helpful to mitigate blackouts and to learn the real time behavior of the power system. As the power system bus voltage angle is closely linked with the behavior of the network, its measurement in real time is very much powerful tool for operating a network [1, 7]. This paper introduces protection scheme depending on comparing the positive sequence voltage magnitude for specified area and positive sequence current phase difference angle for each interconnected line between two areas on the network. The objective of this paper is to present a new wide area measurement technology which will be helpful for monitoring, control as well as protection of power system from sudden large power system disturbance. Also mitigate the chances of blackouts and gives continuous reliable quality supply using fast GPS technology.

Phasor Measurement Unit (PMUs) are high speed power system devices which provides time-stamped synchronized measurements of phasor of voltage and currents in a real time which then be used for calculating voltage and current magnitudes, phase angles, real and reactive power flows, etc. [8]. The synchronization is achieved by the same time sampling of voltage and current waveforms from Global

Positioning System (GPS) satellite timing signals. Synchronized phasor measurement gives the standards of power system monitoring, control and protection of the system to new level [9].The advantage of referring phase angle with reference to global time is helpful for protection, monitoring and control of wide area power system.

## II. PHASOR MEASUREMENT UNIT

### A. Fundamentals of PMUs

PMU is the new technology which provides phasor information (both magnitude and phase angle) in common time reference. This technology is widely acknowledged as one of the most promising development in real time for protection, monitoring and control. The advantage of this new technology of referring phase angle to a global time reference is very much helpful for monitoring wide area network. PMU devices are now installed everywhere in the world to get GPS time synchronized information. With the advancement in technology, the microprocessor based instrumentation such as protection Relays and Disturbance Fault Recorders (DFRs) incorporate the PMU module along with other existing functionalities as an extended feature. Some important applications of PMU are as follows:

- Power system automation in smart grids
- To prevent total system blackout
- Load management and control techniques
- Increase in the reliability of power system
- Wide Area measurement, protection and control, in whole area of regional transmission networks, and local distribution grids.

### B. Classical Definition of PMU

A phasor equivalent of an AC signal $X(t) = Xm\cos(\omega t + \phi)$ is represented as the complex quantities are as follows:

$$X = \frac{Xm}{\sqrt{2}} e^{j\Phi} = \frac{Xm}{\sqrt{2}} (\cos\Phi + j\sin\Phi) \quad (1)$$

$$X = \frac{Xm}{\sqrt{2}} (Xr + jXi) \quad (2)$$

Where $X_r$ and $X_i$ are real and imaginary rectangular components of the complex number phasor value. The magnitude of the phasor is the rms value of sinusoid $(Xm/\sqrt{2})$ and its phase angle is **Φ**, the phase angle of the signal in (1). This is illustrated in fig.1.

Note that positive phase angles are measured in a counter clockwise direction from the real axis. Since the frequency of the sinusoid is implicit in the phasor definition, it is clear that all phasor which are included in a single phasor diagram must have the same frequency. Phasor representation of the sinusoid implies that the signal remains stationary at all times, leading to a constant phasor representation. These concepts must be modified when practical phasor measurements are to be carried out when the input signals are not constant, and their frequency may be a variable. This will be discussed in the next section.

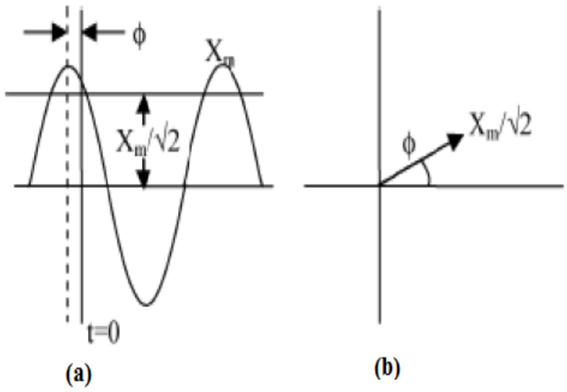



Fig. 1. Phasor representation of sinusoidal signal (a) sinusoidal waveform (b) Phasor reprentation.

### A. Phasor Measurement Concept

PMU is a device that is used to collect and provide instantaneous phasor from desire places of applications, attached with an instantaneous time and date of measuring called time stamped data. Estimated phasor are called as synchrophasor. The phasor that is estimated from samples using a standard time as the reference for a measurement, and has common phase relationship as remote sites.

Although a constant phasor implies a stationary sinusoidal waveform, in practice it is necessary to deal with phasor measurements which consider the input signal over a finite data window. In many PMUs the data window in use is one period of the fundamental frequency of the input signal. If the power system frequency is not equal to its nominal value, the PMU uses a frequency-tracking step and thus estimates the period of the fundamental frequency component before the phasor is estimated. It is clear that the input signal may have harmonic or non- harmonic components. The task of the PMU is to separate the fundamental frequency component and find its phasor representation. Very fast recursive discrete Fourier transform (DFT) calculations are normally used in phasor estimation calculations. In the suggested technique, a positive sequence voltage and phase angle of the positive sequence current is used. Since sampled data are used to represent the input signal, it is essential that antialiasing filters be applied to the signal before data samples are taken. The antialiasing filters are analog devices which limit the bandwidth of the pass band to less than half the data sampling frequency (NY Quist criterion). If Xk {k=1, 2, 3,........, N-1} are the N samples of the input signal taken over one period, then the phasor representation of an input signal is given by

$$X = \frac{\sqrt{2}}{N} \sum_{K=0}^{N-1} xk\, e^{-jK\frac{2\pi}{N}} \quad (3)$$

The peak value of the fundamental frequency thus obtained is then converted to rms value by dividing by $\sqrt{2}$. The DFT calculation eliminates the harmonics of the input signal. However, the non-harmonic signals and any other random noise present in the input signal leads to an error in estimation of the phasor. The error estimation due to these effects has been discussed in the open literatures.

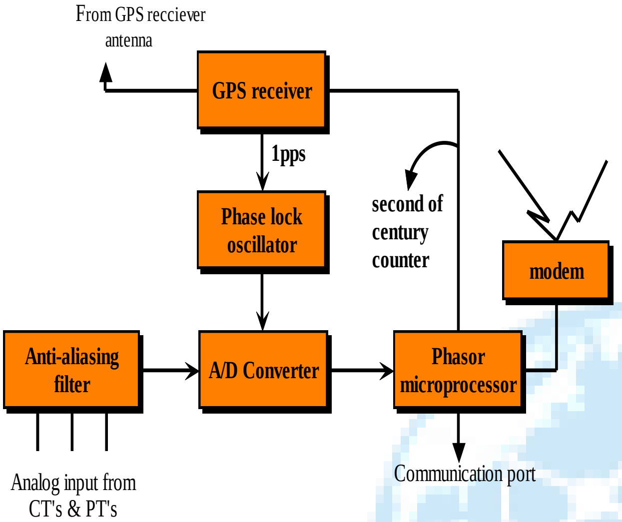



Fig. 2. Block diagram of PMU

Fig.2 shows the analog power signal from current transformer and voltage transformer are converted into digital signal by analog to digital converter (A/D) passed through low pass filter. The GPS signal receiver consists of an antenna and receiver circuits, which detect the 1PPS (pulse per second) synchronizing signal from the GPS satellites A GPS receiver signal provides a precise timing pulse, which then correlates with sampled voltage and current inputs typically the three phase voltages of a substation and the currents in line, transformers and loads terminating at the substation. From these data samples, positive sequence voltage and current are calculated and time stamped so that the exact microsecond when the phasor measurement is taken is permanently attached to it. The data taken can then be transmitted to a remote site over any available communication link. Positive sequence phasor data from all substations equipped with such devices are collected at an appropriate central site using data concentrators or exchanged between local units for protection or control applications. Collecting these measurement data and collating it provides a basic for new, very powerful technique for monitoring, protecting and controlling.

## III. Proposed Technique

The condition of the fault occur on transmission line is mainly detected by two components. First is reduction in voltage of the transmission line because of the fault occurrence. The other component is the direction of the power flow after occurrence of the fault. Fault current direction is determined with the help of phase angle with respect to reference quantity. Direction of fault will be known by comparing the phase angle of the transmission line voltage and current. The main theme of this technique is only to detect the faulted area. Comparison of the measured values of the positive sequence voltage magnitude at main bus for each area is used to achieve this. The result is that, the minimum voltage value which shows the nearest area to the fault. Additionally, the absolute differences of the positive sequence current angles are calculated for all lines interconnected with this faulted area. On comparing these angles with each other, the maximum absolute angle difference value is selected to identify the faulted line. The proposed technique algorithm is as follows.

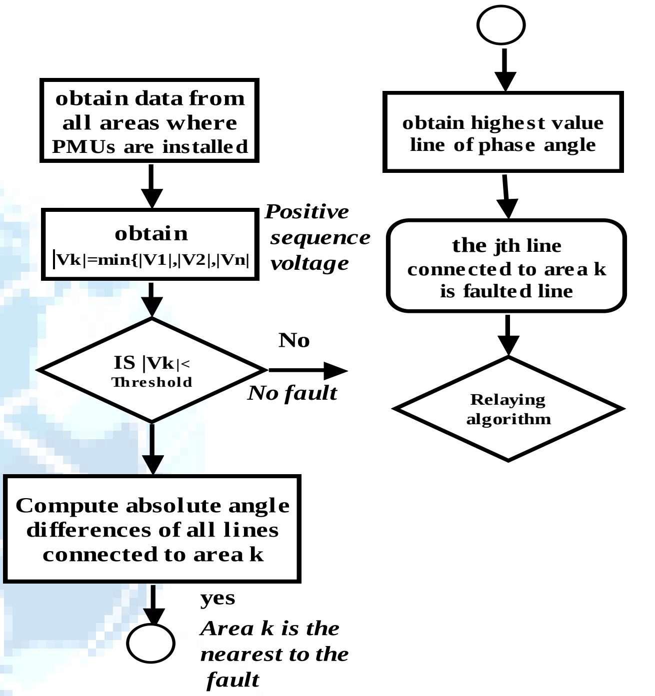



Fig. 3. Algorithm for detection of faulted line

## IV. Simulation Results

The following five bus network is taken for the case study. MATLAB/Simulink package is used to simulate the network and the proposed algorithm is implemented and investigated. The PMU placement is also done as shown in fig.4.

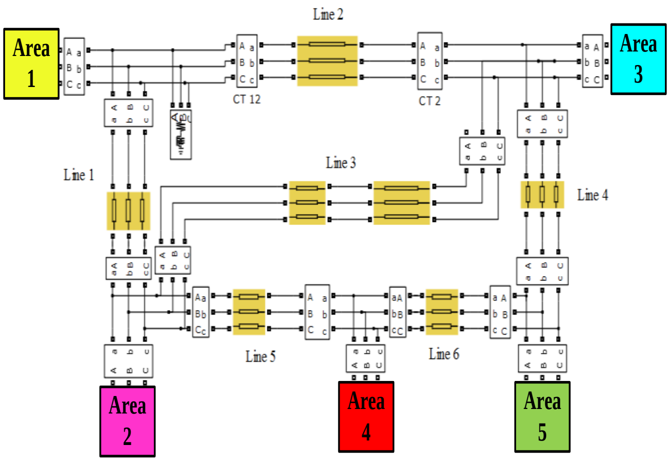



Fig. 4. The five bus system network taken under study

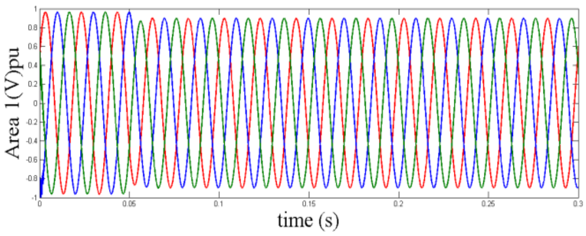
As shown in fig.4 above, 220 KV interconnected transmission line network, 100 km transmission line. Generating station on one side and on the other side is load both are connected through interconnected lines. Different fault conditions are simulated on that line using MATLAB software. The values shown are in per unit on 100 MVA (base) in table no. I.

TABLE I. TRANSMISSION LINE PARAMETER

| | | |
|---|---|---|
| 1 | Generator | 100MVA,220Kv,50Hz,synchronous generator pu model |
| 2 | Transformer | 220 KV/13.8 KV , 100 MVA |
| 3 | Synchronous machine | 13.8 KV, 100 MVA |
| 4 | LOAD 1 | 220kv, 50MW, 24Mvar, RL load |
| 5 | LOAD 2 | 220kv, 100MW, 48Mvar, RL load |
| 6 | LOAD 3 | 220Kv, 80 MW, 38 MVAr, RL load |
| 7 | LOAD 4 | 220kv, 120MW, 58Mvar, RL load |
| 8 | LOAD 5 | 220kv, 150MW, R load |

The transmission line positive and zero sequence parameter are R1=0.10809Ω/km, R0=0.2188Ω/km,L1=0.00092H/km,L0=0.0032H/km,C1=1. 25*10−8f/km,C0=7.85*10−9f/km.The distributed parameter model of transmission line is considered for analysis. A sampling frequency of 20 KHz for a system operating at a frequency of 50 Hz is used in this study. To demonstrate the potential of the approach only few cases of fault occurrence are demonstrated here.

When three phases to ground fault occurs on the transmission line, the faulted signals of three phase voltage signals and three phase current signals are shown below in fig. 5. The fault is located on line 1 connecting area "1" and area "2" as shown in fig 4. When fault occurs, line connected between areas"1" and area"2" is affected. The three Phase to ground faults voltages are shown in fig.5. Three phase current of the lines related to faulted area in fig. 6. Similarly, different fault conditions are simulated on the system using the proposed technique algorithm.



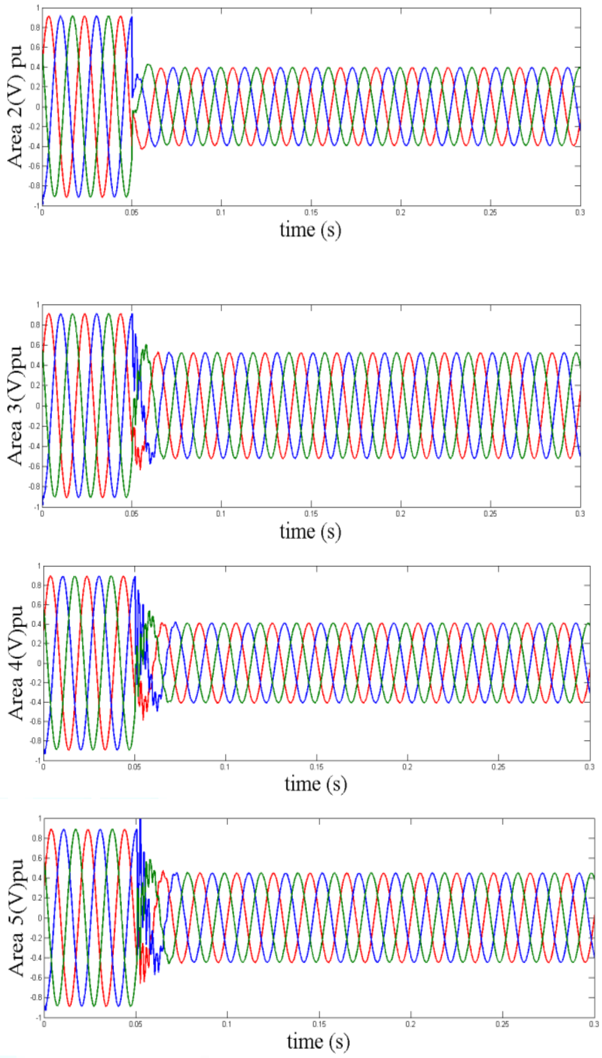




Fig. 5. Three phase voltage signals at each area.

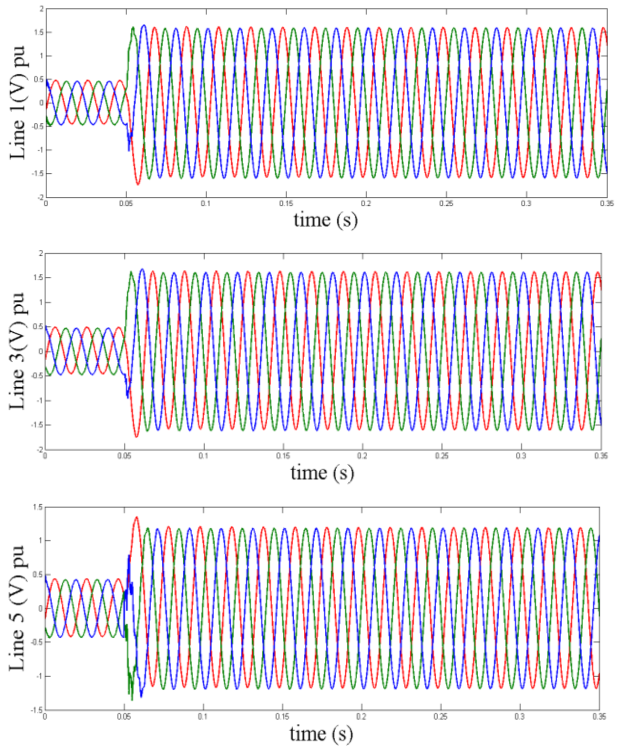



Fig. 6. Three phase current signals for all lines connected to the faulted.

Fig. 7 shows the output from the five PMUs, the graph shows the five positive sequence voltage magnitudes (PSVM) for five different areas during fault. The minimum value is selected which indicates the nearest area to the fault (area “2”). The next step is used to identify the faulted line.

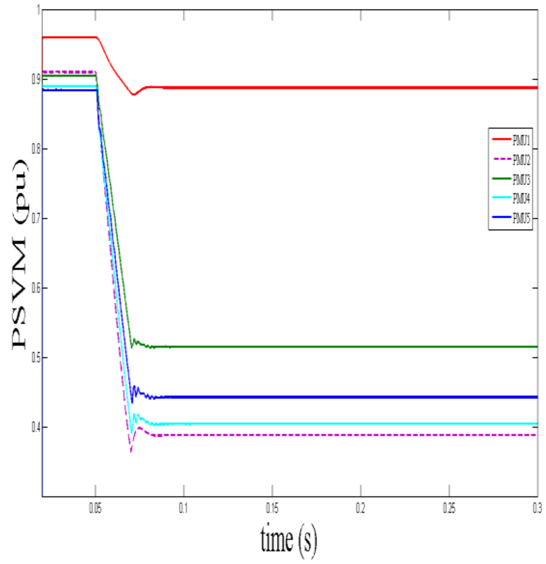



Fig. 7. Positive sequence voltage magnitudes measured from five places on the network.

Fig. 8 shows the absolute differences of positive sequence current angles (PSCA) for all lines connecting the faulted area (area “2”) with all other neighboring areas (areas “1”, “3”, “4”). The graph shows the maximum absolute difference of positive sequence current angle that refers to line 1.

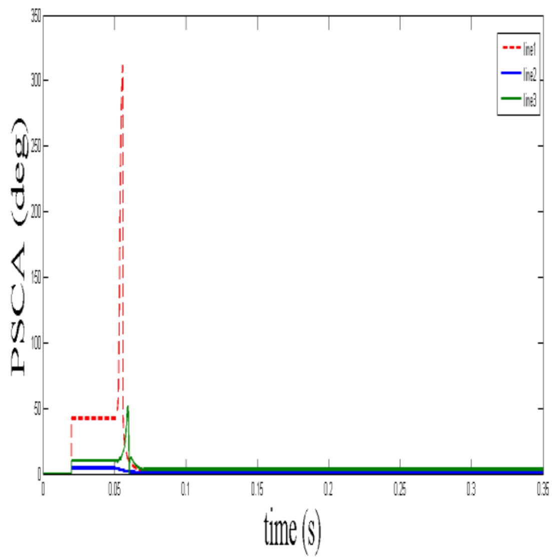



Fig. 8. Positive sequence current angle absolute differences for all lines connected to the faulted area.

A double line to ground fault is located on transmission line 5, see Fig. 4, which connecting area “2” with area “4”. The distance between fault location on the transmission line and the nearest area 4 bus is 60 km. Fig. 9 shows the output from the five PMUs, the graph shows the five positive sequence voltage magnitudes (PSVM) for five different areas during fault. The minimum value is selected which indicates the nearest area to the fault (area “4”). The dotted line represents the area 4.

The next step is used to identify the faulted line. Fig. 10 shows the absolute differences of positive sequence current angles (PSCA) for all lines connecting the faulted area (area “4”) with all other neighboring areas. The graph shows the maximum absolute difference of positive sequence current angle that refers to line 5.

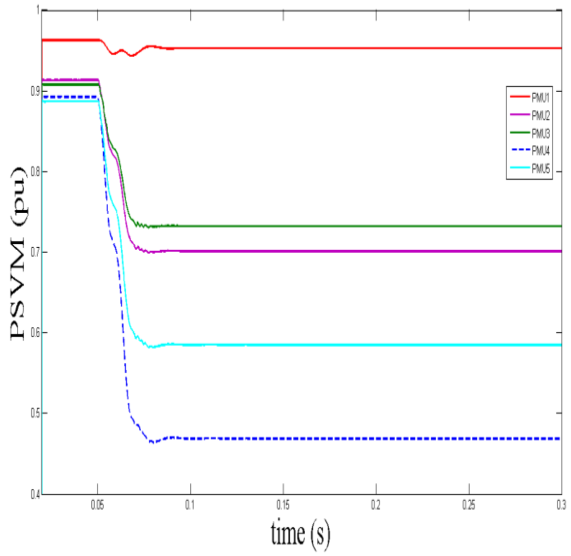



Fig. 9. Positive sequence voltage magnitudes measured from five places on the network.

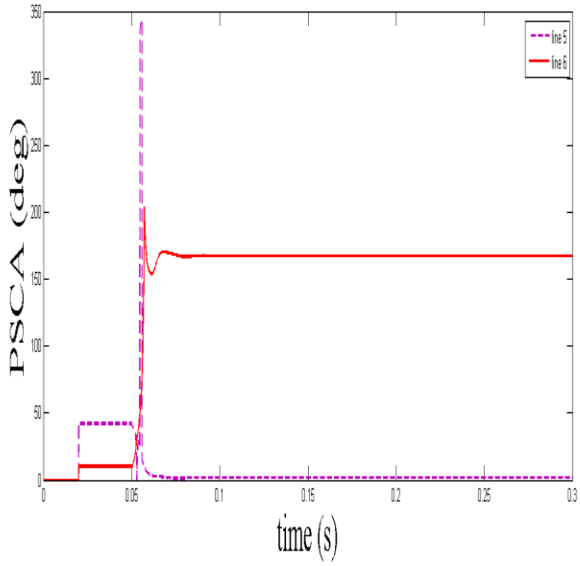



Fig. 10. Positive sequence current angle absolute differences for all lines connected to the faulted area.

A single phase to ground fault is located on transmission line 6, see Fig. 4, which connecting area “4” with area “5”. The distance between fault location on the transmission line and the nearest area 4 bus is 55 km. Fig. 11 shows the five PSVM (Positive Sequence Voltage Magnitudes). The

minimum value is selected to indicate that the nearest area to the fault is area “4”.

The next step is used to identify the faulted line. Fig. 12 shows the absolute differences of positive sequence current angles (PSCA) for all lines connecting the faulted area (area “4”) with all other neighboring areas. The graph shows the maximum absolute difference of positive sequence current angle that refers to line 5.

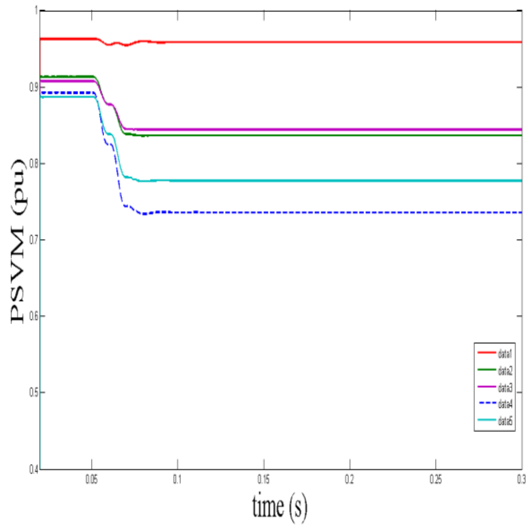



Fig. 11. Positive sequence voltage magnitudes measured from five places on the network.

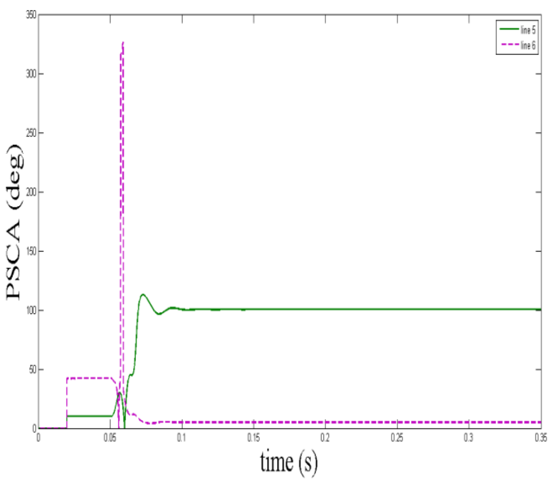



Fig. 12. Positive sequence current angle absolute differences for all lines connected to the faulted area.

## V. CONCLUSION

The paper presents a new protection technique for transmission grids using phasor synchronized measuring technique in a wide area system. The protection scheme has successfully identified the faulted line all over the interconnect system. The algorithm uses the positive sequence voltage and current synchrophasor measured at each line end, and its main objective is to detect different fault locations. Unlike the present techniques, it provides reliable protection to the power system so that it can be applied to any practical power system. Test results from MATLAB simulation seems to be satisfactory.

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**Sayali N. Muneshwar** has obtained B.E. (Electrical) from Govt. College of Engg Chandrapur, India, in 2012. Currently she is pursuing M.Tech in Electrical Power System, from Walchand College of Engg. Sangli, India Under the guidance of Prof. R. P. Hasabe.

**R. P. Hasabe** received the B.E. degree in electrical engineering and the M.E. degree in electrical power systems from Shivaji University, Kolhapur, India in 2001 and 2006, respectively, and is currently pursuing the Ph.D. degree in Electrical engineering at Shivaji University Kolhapur. Currently, he is an Assistant Professor in the Department of Electrical Engineering, Walchand College of Engineering, Sangli. His research interests include power system protection, planning and design, system modeling, and simulation.